

**DAHLGREN DIVISION**  
**NAVAL SURFACE WARFARE CENTER**

Dahlgren, Virginia 22448-5100



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**NSWCDD/TR-95/106**

**NONPARAMETRIC MULTISENSOR TRACK INITIATION  
METHOD FOR NONUNIFORM NONSTATIONARY  
ENVIRONMENTS PART II: A COMPARISON OF M/N AND  
ANMSTI TRACK INITIATION TECHNIQUES APPLIED TO  
THE WALLOPS ISLAND MULTISENSOR INTEGRATION  
EXPERIMENT**

**BY ROBERT J. PAWLAK, PH.D.      RON A. STAPLETON**

**SHIP DEFENSE SYSTEMS DEPARTMENT**

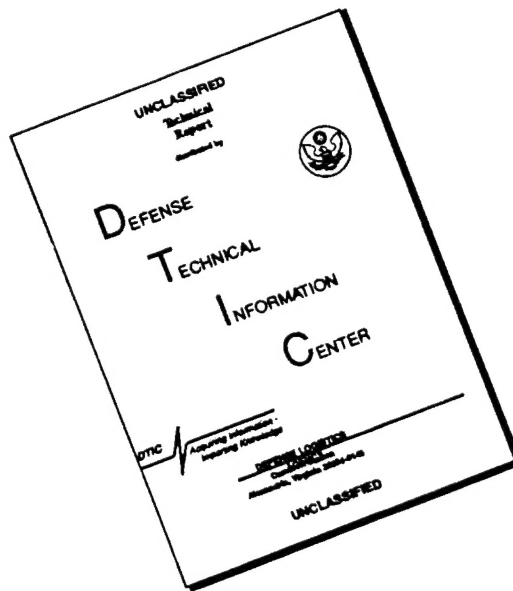
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13. ABSTRACT (Maximum 200 words)  This follow-on report compares the performance of the adaptive nonparametric multisensor track initiation (ANMSTI) algorithm to that of conventional M out of N (M/N) track initiation algorithms, for a test set composed of concurrent radar and infrared search and track (IRST) data. To present a fair comparison of the various techniques, both false track initiation rates and track initiation times are analyzed in this report. While the analysis shows that some of the M/N techniques provide better track initiation times than the ANMSTI approach, some of these same techniques have false track initiation rates that in cluttered environments render them almost useless. Furthermore, it is shown that the ANMSTI algorithm is capable of regulating its false track initiation rate, whereas the M/N algorithms cannot. When comparing the time to first track initiation of single-sensor and dual-sensor M/N techniques, most of the benefits of using a dual-sensor M/N track initiation criteria are shown to accrue when the track initiation criterion is relatively strict (i.e., usually when false alarm rates from the sensors are high).				
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## FOREWORD

Considerable Department of Defense and industry resources have focused on methods for real-time integration of multisensor data. When considered in the context of sensor search systems, these methods typically combine information at either the detection or track level. This follow-on report discusses the results obtained when applying an adaptive nonparametric multisensor track initiation (ANMSTI) technique to the fusing of information at the detection level. While this report discusses the application of the ANMSTI technique to a radar/infrared sensor suite, the algorithm has wide areas of applicability, and could be employed for suites of active sensors as well.

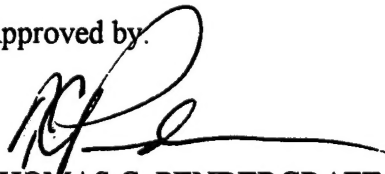
The advantages of using an ANMSTI technique include real-time robust operation, the ability to work in nonstationary environments, and the ability to work with single- or dual-sensor data. The purpose of this report is to quantify exactly how much reaction time can be gained from using the ANMSTI approach on dual-sensor data in relatively benign environments. Reaction time differences, along with differences in false track initiation rates are obtained by comparing ANMSTI results to results obtained with a conventional M out of N (M/N) track initiation technique. The data used for testing the algorithms were from the Wallops Island Multisensor Integration (MSI) Experiment, held on November 1993 through March 1994.

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This report has been reviewed by B. J. Barnes, Head, Sensors Integration Branch and Stuart A. Koch, Head, Search and Track Division.

Approved by:



THOMAS C. PENDERGRAFT, Head  
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## INTRODUCTION



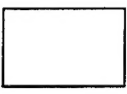
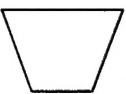
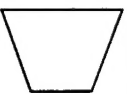
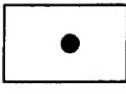
This report compares the result of an adaptive nonparametric multisensor track initiation (ANMSTI) algorithm<sup>1</sup> to that of a conventional M out of N (M/N) track initiation approach.<sup>2</sup> In essence, both of these algorithms use the previous  $N$  scans of sensor data to initiate a track whenever track initiation criteria are met.

For M/N-based approaches, the criteria consist of the number of scans having data that correlate spatially for each sensor. That is, the number of correlating scans is totalled for each sensor: call this  $m_I$  for the infrared search and track (IRST) and  $m_R$  for the radar. Each total is compared to a threshold ( $M$ ), and if  $m_I$  or  $m_R$  exceeds  $M$ , a track is initiated. For dual-sensor M/N techniques, a track is initiated when  $m_I + m_R$  exceeds  $M$ .

Greatly simplified, the ANMSTI algorithm is essentially similar to the M/N approach except that it allows  $M$  to vary during operation, weights  $m_I$  and  $m_R$ , and is adaptive. Also, data are processed differently according to spatial location (i.e., it has built-in spatial clutter mapping). This gives the ANMSTI algorithm the ability to maintain a constant false track initiation rate in environments that consist of areas of locally high false-alarm rate data mixed with a lower false-alarm rate background. However, because clutter densities were very low in most cases observed for this comparison report, and because clutter was almost spatially uniform as a result of the limited fields of regard of the particular sensors, this spatial processing was not necessary. An overview of the ANMSTI algorithm can be found in Pawlak 1992,<sup>1</sup> and details of the implementation of the algorithm can be found in Stapleton, et al. 1993.<sup>3</sup>

To ensure a fair comparison, the dimensions of the spatial gates used for the M/N and ANMSTI approaches were identical. Thus, none of the performance differences considered for this report were caused by mismatches in the sizes of the spatial gates. Table 1 illustrates how the gating operation was performed when different types of data were correlated. For example, in the elevation dimension, only IRST-to-IRST correlation was performed, and the gate was over a fixed region in elevation. The gate center position is the location in elevation of the current detection. A pictorial example of how the gating correlation process would operate for the case where both IRST and radar detections are present is shown in Figure 1, along with the calculated values of  $m_I$ ,  $m_R$ , and  $m_I + m_R$ . For this example, a track initiation would result for  $M=2$  using the 2/3 Horizon Infrared Surveillance Sensor (HISS), 2/3 Short Range Radar (SRR) and 2/3 dual criteria. Track initiation would not result for the 3/3 SRR criterion, or 3/3 HISS, but would result for the 3/3 dual criteria. It should be noted at this point that it is possible for track initiation to occur on the 2/3 SRR criteria even though an IRST detection is the current detection. Further details on how the gates were implemented can be found in Stapleton, et al. 1993.<sup>3</sup>

TABLE 1. GATING ALGORITHM\*

Data Type/Dimension							
Data Type/ Dimension			IRST		Radar		
			Azimuth	Elevation	Azimuth	Elevation	Range
	IRST	Azimuth					
		Elevation					
	Radar	Azimuth					
		Elevation					
		Range					

\* Spatial dimension is on X axis; time dimension is on Y axis; totally shaded table cell indicates *not applicable* or *test not performed*; black dot indicates a predicted value (in the case of radar-to-radar range correlation, this predicted position is found using a linear interpolation calculated by averaging the range rates from the two measurements and using the range from the current measurement).

The data used for testing the algorithms were obtained from the Wallops Island Multisensor Integration (MSI) Experiment, held November 1993 through March 1994. IRST data were provided by the HISS, while radar data were from the Ku-band instrumentation radar (the SRR). The characteristics of these sensors can be found in Appendix A. The target used in the test was a TLX-1 towed target, modified to have a reduced radar cross section and fitted with a device to provide infrared (IR) augmentation. The TLX-1 target, which is a missile-shaped drone that is towed behind a Lear aircraft, flew at altitudes varying from 30 to 250 ft. Detections from the higher altitude Lear



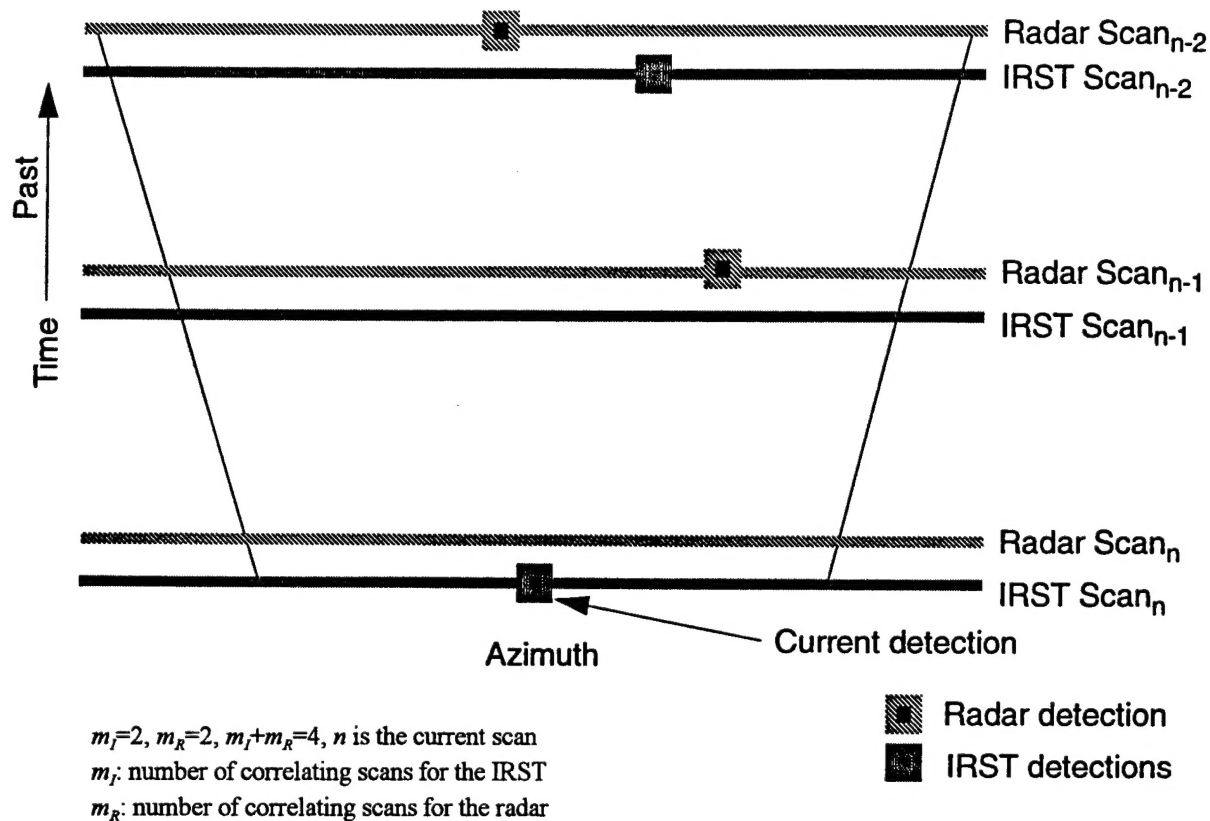


FIGURE 1. ILLUSTRATION OF GATING PROCEDURE IN AZIMUTH FOR IRST-TO-RADAR CORRELATION

aircraft were present in much of the original data, but were removed for the purposes of evaluating the track initiation approaches. However, radar detections resulting from cues were *not* removed from the data. A total of 19 runs of data were used for comparing the two algorithmic approaches.

The sensor integration concepts being explored have the most payoff against high-speed, low-elevation, anti-ship cruise missile targets that are very difficult for a stand-alone radar sensor to detect and engage. During the Wallops Island test, even though a great deal of valuable data were gathered, there were difficulties with the targets because of their increased radar signature, reduced IR signature, and relatively high altitude when compared to projected tactical threats. As a result, the radar often had a significantly better detection range than the IR system; for this reason the results presented in the next section should be interpreted realizing that the performance difference between the two sensors was partially due to a target which was not wholly realistic.

**Note:** A few words need to be said about the interpretation of test data used for the comparison: Because radar cues were incorporated in the processing, in effect a "radar" M/N track initiation has possibly incorporated IR data to start the track. Thus, the performance of the M/N SRR techniques needs to be interpreted with a jaundiced eye, because dual-sensor data were used about

50 percent of the time to start a track. In the remaining 50 percent of the cases, past IR data were ignored in the track initiation process. As a result, this report cannot be interpreted as a validation of single-sensor versus dual-sensor track initiation techniques. Instead, the report should be interpreted as an examination of techniques that employ dual-sensor data, with some of the techniques being easier to implement (the M/N criteria), and others offering more consistent performance even under high-clutter conditions (the ANMSTI technique).

## RESULTS OF COMPARISON

Track initiation times and false track initiation rates were tabulated for both M/N single-sensor techniques and M/N dual-sensor techniques, and for the ANMSTI algorithm. Track initiations from all algorithms were classified as either target, clutter/noise, or other bona fide object. The first time at which a track was started on the TLX-1 by a particular algorithm is defined as the time to first track initiation. The number of clutter/noise track initiations was also tabulated, and this number was divided by the total run time to obtain the false track initiation rate. Note that "single-sensor" techniques are included for the sake of comparison, and the use of such techniques would mean that past data from one sensor are possibly ignored (negating some of the benefit from using both sensors—see note on previous page).

Table 2 shows the difference in time to first track initiation for the ANMSTI and M/N approaches. That is, the tabulated numbers can be expressed as

$$\Delta \text{ time} = \text{M/N time to first track initiation} - \text{ANMSTI time to first track initiation}$$

Clearly, a positive time difference means that the ANMSTI algorithm initiated a track before the M/N technique in question. Also, the airspeed of the TLX-1 was approximately 284 kn, meaning that a time difference of 1.0 sec corresponds to a difference in range of approximately 0.08 nmi.

Table 3 tabulates the false track initiation rate (FTIR: defined as the number of false track initiations per second). As a means for evaluation, this number was set at  $\leq 0.1$ , which corresponds to a false track initiation provided to the tracker about once every 10 sec. Ideally, the number of false track initiations should be as small as possible, especially in high-clutter environments where false tracks can persist for long spans of time. Unless the number of these false tracks is limited, a catastrophic loss of track processor function could occur, in which case the operation of a multisensor suite would be so degraded as to be unusable.

Note that mean times are tabulated at the bottom of each column of Tables 2 and 3. In the mean values in Table 2, the 2/3 SRR and 2/3 dual-sensor M/N track initiation delta times are better than those of the ANMSTI approach. However, Table 3 shows that the dual 2/3 technique has a mean false track initiation rate that exceeds 0.1, which is excessive. The 2/3 SRR M/N approach offers good performance at a reasonably low false track initiation rate; however, the use of this technique means that past HISS data are ignored in the track initiation process, which is a factor when considering three-dimensional (3-D) track initiation performance. The trade-off between track

TABLE 2. TIME TO FIRST TRACK INITIATION\*

Data Set	2/3 HISS delta time (sec)	2/3 SRR delta time (sec)	2/3 Dual delta time (sec)	3/3 HISS delta time (sec)	3/3 SRR delta time (sec)	3/3 Dual delta time (sec)	Background Contamination
701407	97.3	0.0	0.0	113.1	86.7	86.7	Present
701438	16.6	0.0	0.0	46.6	17.2	16.6	Not Present
701453	0.0	52.0	0.0	53.0	83.3	51.4	Not Present
741416	7.7	0.0	0.0	14.9	9.6	8.3	Present
741434	200.4	-41.6	-43.5	206.1	220.7	206.1	Present
811856	0.0	-56.7	-56.7	4.4	92.4	4.4	Present
811933	14.1	-0.8	-0.8	15.3	99.8	0.0	Present
812008	58.8	0.0	0.0	91.6	61.4	3.0	Not Present
821328	24.4	-4.9	-4.9	30.0	59.1	1.0	Not Present
821348	10.6	-10.8	-10.8	58.8	-10.6	-10.6	Present
821403	6.2	-35.6	-35.6	100.3	-35.1	-35.1	Present
821421	0.4	-19.7	-19.7	NS**	-19.5	-19.5	Present
831519	50.3	-97.5	-97.5	52.0	0.0	0.0	Present
891829	-2.8	8.0	-2.8	0.0	8.6	0.0	Present
891848	-5.8	-5.6	-5.8	237.6	19.1	-5.8	Present
891923	1.1	-64.9	-64.9	2.7	0.0	0.0	Present
901317	6.7	-22.6	-22.6	9.6	0.2	0.0	Present
901338	39.7	-56.0	-56.0	44.0	40.7	39.7	Present
901358	86.1	0.0	0.0	96.1	0.2	0.2	Present
Mean	32.2	-18.8	-22.2	65.3	38.6	18.2	

\* Bold lines around data indicate which sensor detected the target first (i.e., if cell with bold lines is in SRR column, then the SRR detected the target first). Shading indicates data sets where the HISS had a high false-alarm rate.

\*\* Not specified: The 3/3 HISS track initiation criteria failed to initiate a track on the target in this data set. This value is not counted in the mean. However, the reader must realize that this represents a total failure of this track initiation criteria for this data set.

initiation time and false track initiation performance is perhaps best illustrated by a trade-off chart as shown in Figure 2. In this plot, the best performing algorithm is at the upper right. Points to the left of the solid vertical line have an excessive false track initiation rate, and would not be suitable for an MSI system.

TABLE 3. FALSE TRACK INITIATION RATE (FTIR)\*

Data Set	ANMSTI FTIR (sec <sup>-1</sup> )	2/3 HISS FTIR (sec <sup>-1</sup> )	2/3 SRR only, FTIR (sec <sup>-1</sup> )	2/3 Dual FTIR (sec <sup>-1</sup> )	3/3 HISS FTIR (sec <sup>-1</sup> )	3/3 SRR FTIR (sec <sup>-1</sup> )	3/3 Dual FTIR (sec <sup>-1</sup> )
701407	0.0205	0.0205	0.0	0.0205	0.0	0.0	0.0
701438	0.0423	0.0458	0.0	0.0458	0.0	0.0	0.0
701453	0.0420	0.0310	0.0066	0.0553	0.0	0.0	0.0066
741416	0.0075	0.0	0.0075	0.0302	0.0	0.0	0.0
741434	0.0363	0.0182	0.0234	0.0649	0.0	0.0052	0.0311
811856	0.0062	0.0493	0.0	0.0554	0.0	0.0	0.0
811933	0.0254	0.0254	0.0381	0.1843	0.0	0.0	0.0254
812008	0.0587	0.0377	0.0419	0.0629	0.0	0.0	0.0461
821328	0.0643	0.8417	0.01601	0.9060	0.0161	0.0	0.0429
821348	0.078	0.5801	0.2194	0.9360	0.1072	0.0049	0.3754
821403	0.0657	1.011	0.1095	1.2270	0.1408	0.0	0.3536
821421	0.1279	0.4264	0.0256	0.5116	0.0171	0.0	0.0597
831519	0.0	0.0	0.0168	0.0168	0.0	0.0	0.0
891829	0.0078	0.0078	0.0	0.0078	0.0	0.0	0.0078
891848	0.0550	0.4350	0.1310	0.4455	0.3538	0.0	0.4140
891923	0.0038	0.0230	0.0153	0.0306	0.0	0.0077	0.0077
901317	0.0980	0.1680	0.1470	0.4829	0.0490	0.0070	0.1960
901338	0.0269	0.8275	0.3331	1.2250	0.0484	0.0108	0.4997
901358	0.0246	0.0197	0.0443	0.0837	0.0	0.0099	0.0296
Mean	0.0416	0.2404	0.0619	0.3364	0.0386	0.0024	0.1102

\* Bold lines around data indicate which sensor detected the target first (i.e., if cell with bold lines is in SRR column, then the SRR detected the target first). Shading indicates data sets where the HISS had a high false-alarm rate.

It also appears from Figure 2 that the addition of the HISS sensor data did little to affect track initiation time, and served to increase false track initiation rate. However, in about 50 percent of the cases, as previously stated, IR data resulted in cues which were subsequently used in the SRR M/N criteria. Additionally, the analysis in this report does not include the time to achieve a 3-D track

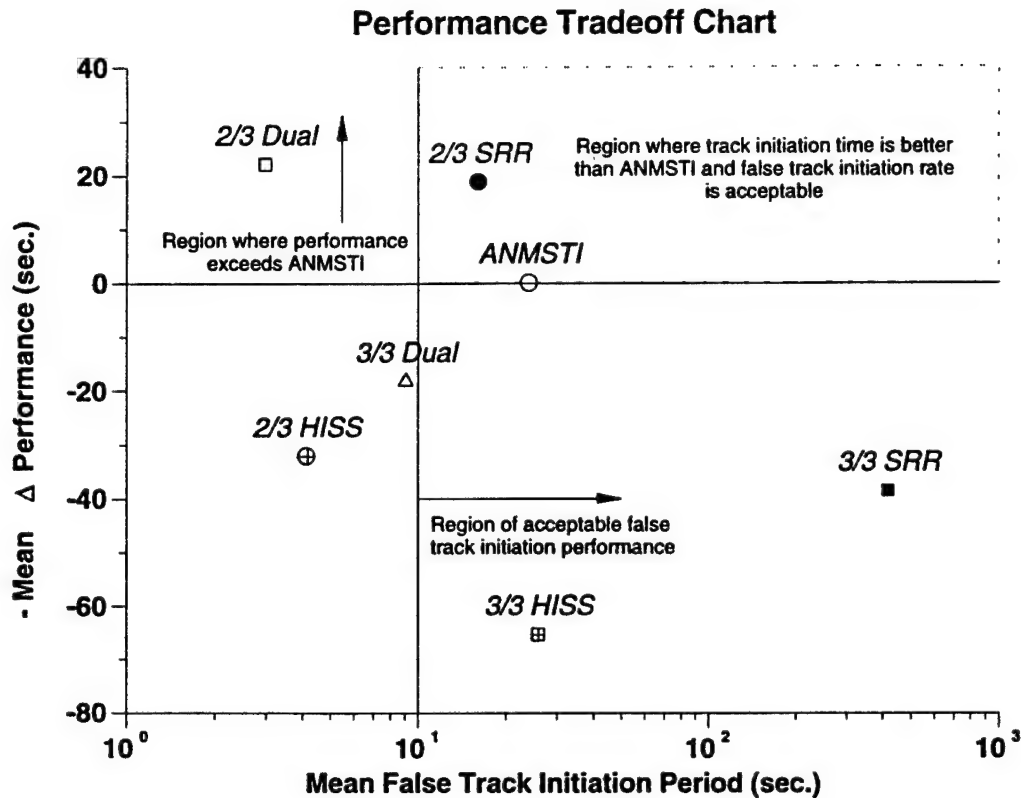


FIGURE 2. RELATIVE PERFORMANCE (MEAN) OF ANMSTI AND M/N APPROACHES  
(PERFORMANCE INCREASES TO RIGHT AND UPWARD)

initiation,\* which is perhaps a better indicator of when a firm track might be established on a target (although track update strategies are also a factor in transitioning to a firm track).

In examining the track initiation times for the 2/3 HISS, 2/3 SRR and 2/3 dual criteria shown in Table 2, it is evident that there is little to be gained in track initiation time from using a dual M/N technique when  $M=2$ . In fact, there are only two instances where the performance of a dual-sensor M/N criterion showed performance that exceeded that of the single-sensor M/N techniques (data sets 741434 and 891829). However the results from comparing 3/3 techniques are somewhat different, showing a clear benefit to using a dual-sensor track initiation criteria (data sets 701438, 701453, 741416, 811933, 812008, 821328, 891848, 901317, 901338). Thus, the use of a dual-sensor M/N track initiation criteria should not be discounted.

It would be stressed that the data used for comparing the algorithms were not well suited for the application of the ANMSTI technique. The ANMSTI algorithm requires that there be either

\*A 3-D track initiation is one that contains both radar and IR data.

clutter data, or the complete absence of other target detections before valid detections are received by the algorithm. In a normally functioning multisensor search and track system this would be the case. However, the effective application of the ANMSTI technique was hampered by the lack of a track processor (which would ensure the removal of data from existing targets). Examination of the last column in Table 2 shows that in many instances (79 percent) the target was immediately present in the field of view, or other target data were immediately present. This has a very negative effect on the performance of the ANMSTI algorithm, as a result of contamination of the background estimate. In fact, for the four data sets in which there is no background contamination, the ANMSTI algorithm has track initiation times that are very close to the best attainable for those runs. The performance of the ANMSTI algorithm would be greatly improved if a functional track processor was present, while the track initiation time for the M/N algorithms would not change with the incorporation of a track processor.

An example of background contamination is shown in Figure 3, where data set 821328 is plotted. Here another target is present (132 deg azimuth, 40 sec) in the field-of-view before the target of interest (134 deg, 105 sec). This plot also illustrates the high-clutter densities that are sometimes present in the HISS data. These high densities occurred in about 25 percent of the cases analyzed, constituting two days' worth of data out of seven days' data examined for this report. Admittedly, this represents a small sample over the number of days that testing was actually conducted.\*\* In fact, on days that were not included in this analysis, false-alarm rates tended to be generally lower.

The behavior of a track processor can be simulated by removing the contaminating data from the background estimate. The results of such a process are summarized in Table 4, for data set 821328. The table shows that while the track initiation time delta for the ANMSTI algorithm did not improve (and in fact decreased slightly), the false track initiation rate decreased by a factor of three. This seems to suggest that from a track initiation standpoint, one of the major functions of the track processor is to help decrease the number of false track initiations.

For additional insight, differences in performance between ANMSTI and all M/N techniques with  $N=3$  and  $M \geq 2$  can be tabulated and plotted as in the relative frequency plot shown in Figure 4. This plot illustrates that most of the time the performance of the ANSMTI approach exceeds that of the aggregate performance of all the M/N-based approaches.

Finally, re-examining the data in the first column of Table 3 indicates that the ANMSTI algorithm is capable of maintaining a relatively constant false track initiation rate. For the M/N approaches, this rate tends to vary substantially, or to be much lower or higher than desired. In fact, for the ANMSTI algorithm, the standard deviation of the false track initiation rate was only 0.0345.

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\*\*These nineteen data sets represent the only instance when dual-sensor data were present for the TLX-1 target.



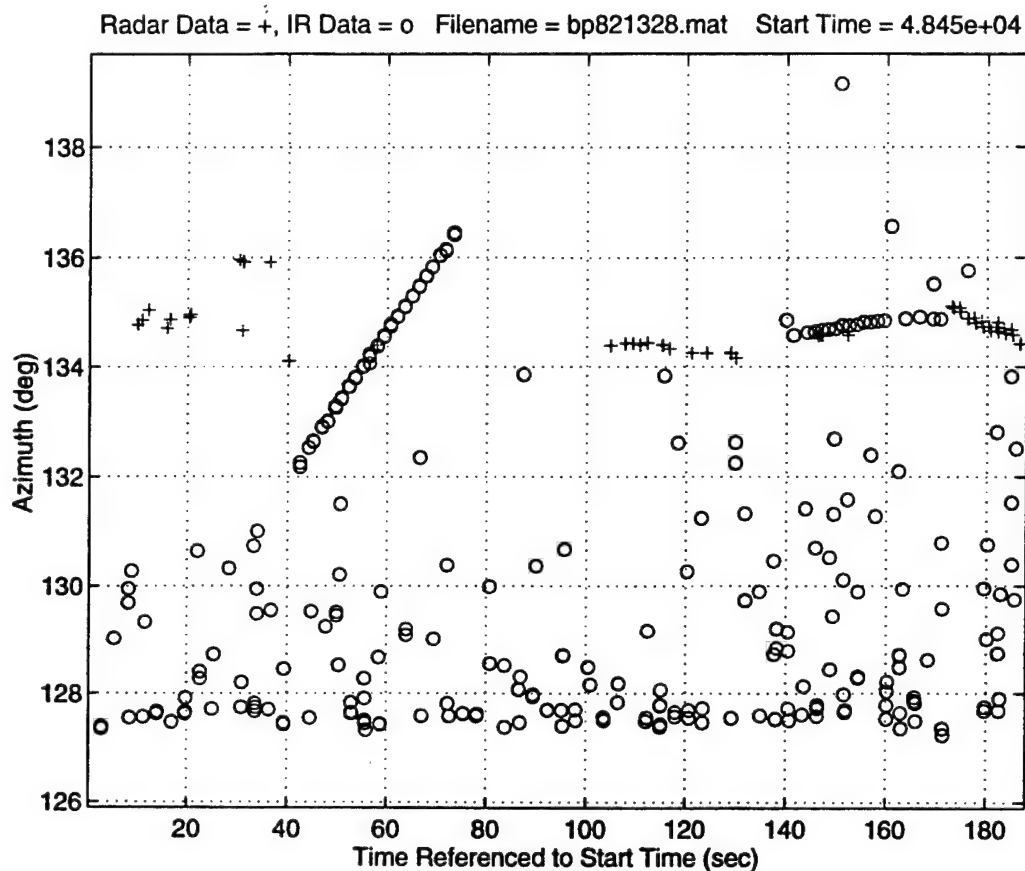


FIGURE 3. AZIMUTH PLOT OF DATA SET 821328 ILLUSTRATING BACKGROUND CONTAMINATION AND HIGHIRST CLUTTER DENSITY

TABLE 4. TIME TO FIRST TRACK INITIATION AND FALSE TRACK INITIATION RATE FOR DATA SET 821328, BACKGROUND CONTAMINATION REMOVED

Data Set	2/3 HISS delta time (sec)	2/3 SRR delta time (sec)	2/3 Dual delta time (sec)	3/3 HISS delta time (sec)	3/3 SRR delta time (sec)	3/3 Dual delta time (sec)	Background Contamination
821328 (Mod.)	24.1	-5.2	-5.2	29.0	58.1	0.0	Not Present
ANMSTI FTIR sec <sup>-1</sup>	2/3 HISS FTIR sec <sup>-1</sup>	2/3 SRR FTIR sec <sup>-1</sup>	2/3 Dual FTIR sec <sup>-1</sup>	3/3 HISS FTIR sec <sup>-1</sup>	3/3 SRR FTIR sec <sup>-1</sup>	3/3 Dual FTIR sec <sup>-1</sup>	
0.0268	0.8587	0.0134	0.8909	0.0161	0.0	0.0322	

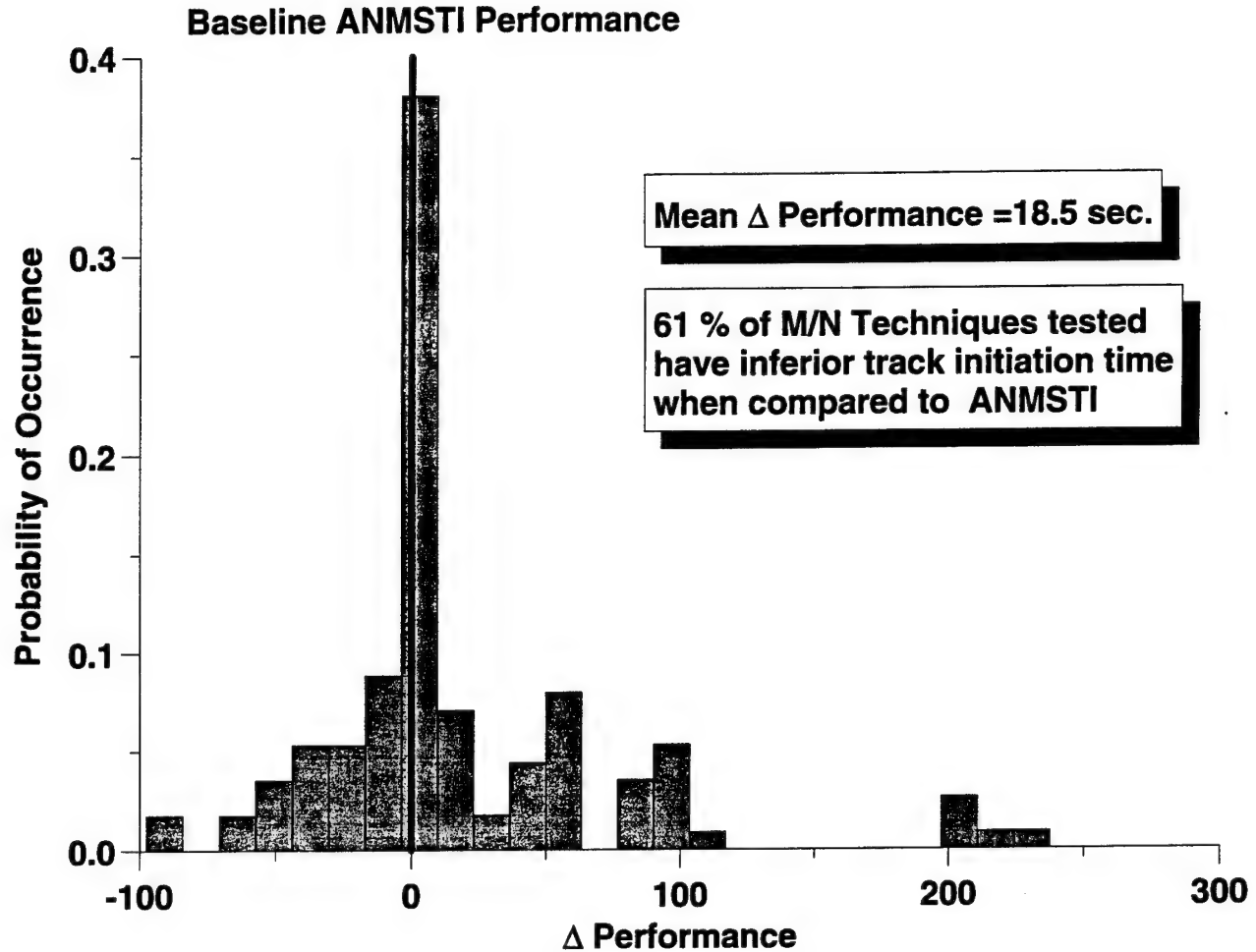


FIGURE 4. RELATIVE FREQUENCY PLOT COMPARING RELATIVE TRACK INITIATION PERFORMANCE OF M/N AND ANMSTI ALGORITHMS

### CONCLUSION

It is obvious from examining the data that no single M/N-based approach is suitable for use as a multisensor track initiation algorithm. If the track initiation time of one of the M/N approaches is good, then its false alarm performance is typically bad. Thus, there is a trade-off between these two types of performance. The analysis of the test data shows the ANMSTI approach capable of finding a good point on the trade-off curve, and of changing its performance as conditions warrant. The analysis also shows that multisensor track initiation is most useful in limiting the number of false track initiations when the false alarm rates of the sensor data are high (i.e., a relatively strict criteria for track initiation is necessary).



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**APPENDIX A**

**SENSOR CHARACTERISTICS FOR WALLOPS ISLAND  
MULTISENSOR INTEGRATION TEST**

During the Wallops Island Multisensor Integration (MSI) Experiment (November 1993–March 1994), infrared search and track (IRST) data were provided by the Horizon Infrared Surveillance Sensor (HISS) and radar data were from a Ku-band instrumentation radar known as the Short Range Radar (SRR). Characteristics of these sensors are summarized in Table A-1.

TABLE A-1. SENSOR CHARACTERISTICS

SHORT RANGE RADAR	
Transmit power	6.5 kW peak, 5% duty cycle
Frequency	16.15 to 16.65 GHz
Antenna type	Parabolic dish
Antenna gain	44 dB
Antenna beamwidth	0.8 x 0.8 deg Az x El
Antenna scan pattern	Programmable raster scan
Polarization	Horizontal
Waveform type	Medium PRF Pulse Doppler
Track-while-scan or dedicated closed loop track operation	

HORIZON INFRARED SURVEILLANCE SENSOR	
Operating band	3.8 to 4.2 $\mu$
Instantaneous field of regard	80 x 80 $\mu$ rad
Vertical field of view	1.17 deg
Horizontal field of regard	15 deg
Update rate	1 Hz
Scan pattern	Nutating scan in azimuth
NEI	$2 \times 10^{-14}$ W/cm <sup>2</sup> -steradian
Sensor design basis	Imager
Stabilization	Mass
Processing	Single scan detection

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